Design studies for the 3 GeV MAXIV storage ring

Erik Wallén

On behalf of the accelerator physics group at MAX-lab

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Some small-emittance light-source lattices with multi-bend achromats

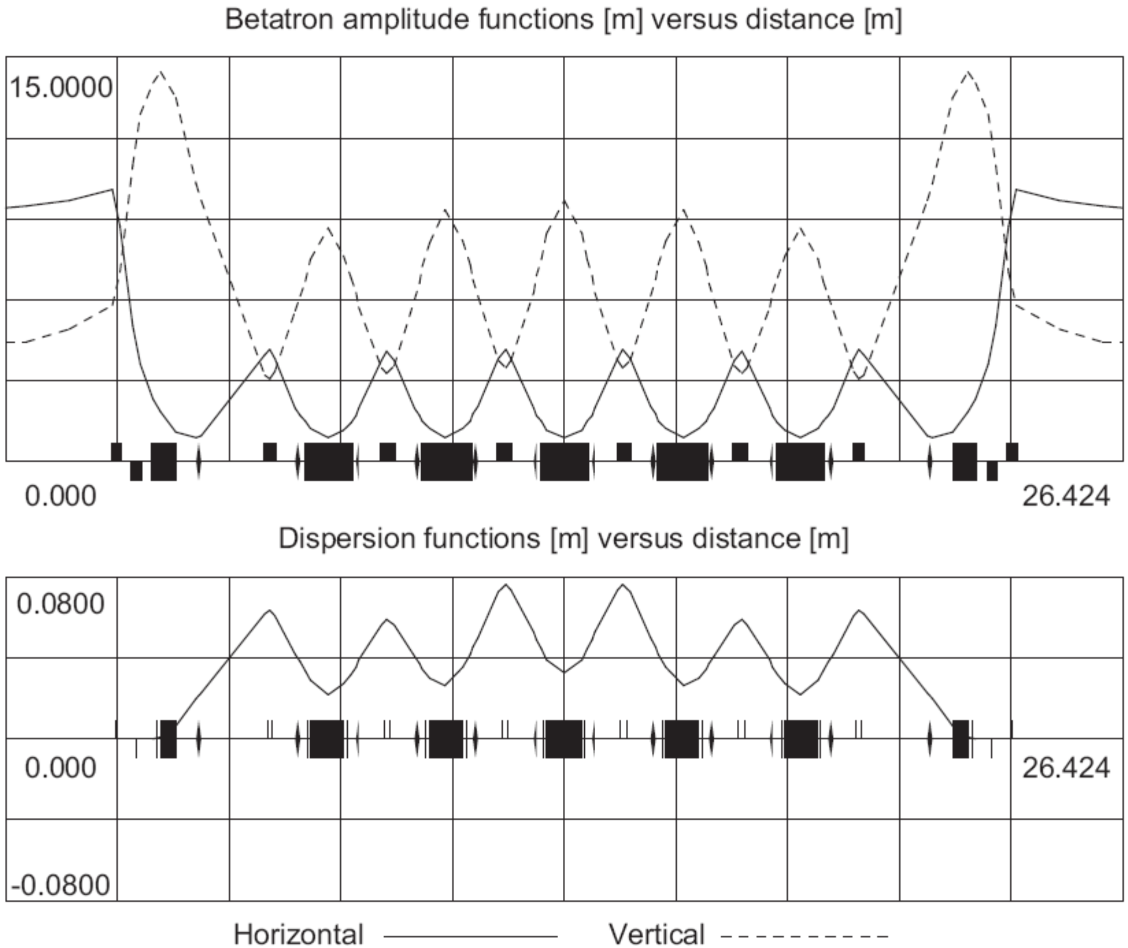
M. Eriksson[a,*], L.-J. Lindgren[a], M. Sjöström[a], E. Wallén[a], L. Rivkin[b], A. Streun[b]

[a] *MAX-lab, Ole Romers v. 1, Box 118, S-22100 Lund, Sweden*
[b] *Paul Scherrer Institute, 5232 Villigen PSI, Switzerland*

Main machine parameters for the two rings

Number of achromats	12	20
Operating energy (GeV)	3	3
Circulating current (A)	0.5	0.5
Bunch pattern	Even fill	Even fill
Circumference (m)	318	530
Length of achromat (m)	26.5	26.5
Number of straight sections	12	20
Length of straight sections (m)	5	5
Horizontal emittance (nm rad)	1.25	0.31
Horizontal emittance incl. IDs and IBS (nm rad)	0.95	0.24
Vertical emittance (nm rad)	0.009	0.009
Natural energy spread (%)	0.093	0.074
Energy spread incl IDs (%)	0.099	0.085
Betatron wave numbers (hor/vert)	26.4/9.4	42.4/14.4
Corrected chromaticities (hor/vert)	1/1	1/1
Momentum compaction factor	7.2×10^{-4}	2.6×10^{-4}
Energy loss/turn, naked lattice (keV)	605	363
Energy loss/turn with IDs (keV)	946	766
Horizontal dynamic aperture (mm)	−15/+18	−15/+18
Vertical dynamic aperture (mm)	−10/+10	−8/+8
Hor. physical half-aperture (mm)	13	13
Vert. physical half-aperture in straight sections (mm)	2	2
Energy acceptance (%)	6	7.7

The magnet lattice for the 20-cell-achromat lattice.



Twiss function of a 7-bend achromat.

Each achromat consists of five central unit cells with a vertically focusing dipole magnet between horizontally focusing quadrupoles.

A longitudinally varying dipole field is introduced in the dipole*. Each dipole magnet has a stronger magnet field in the central part than at the ends.

Two vertically defocusing sextupoles correcting for the vertical chromaticity flank each dipole magnet.

The horizontally focussing quadrupole magnet contains the sextupole component correcting the horizontal chromaticity.

The unit cells are flanked by matching cells yielding the zero dispersion and suitable b-functions for the straight sections.

The lattice is very compact in the sense that the horizontal betatron wavelength is short (13m at 3 GeV).

The multipole components are large so the magnet apertures must be kept small to avoid saturation in the magnet iron yokes.

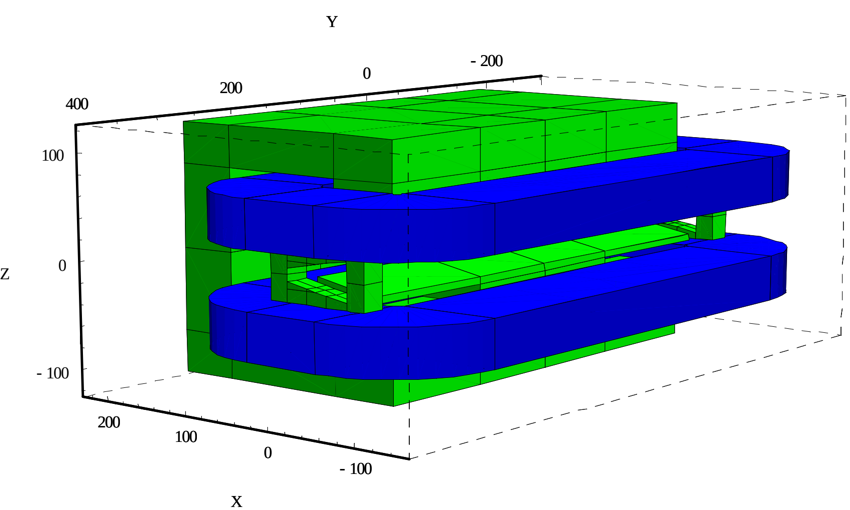
*R. Nagaoka, A. Wrulich, Nucl. Instr. and Meth. A 575 (2007) 292.

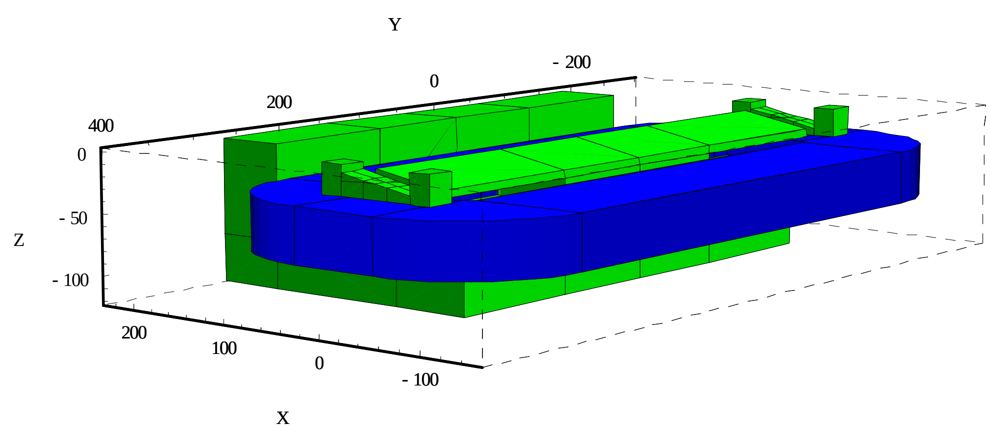
Magnet parameter values for the 12 cell ring

	Length (m)	Dipole (T)	Quadr (T/m)	Sext (T/m^2)
Unit cell dipole	$0.8/2 \times 0.15$	0.92/0.46	$-8/-4$	0/0
Matching dipole	0.4/0.15	0.92/0.46	$-8/-4$	0/0
Unit cell quad	0.3	0	40	710
Matching foc quads	0.3	0/0	40	0/0
Matching defoc quad	0.3	0	-25	0
Sextupole	0.1	0	0	1430

High-field dipole part/low-field dipole part.

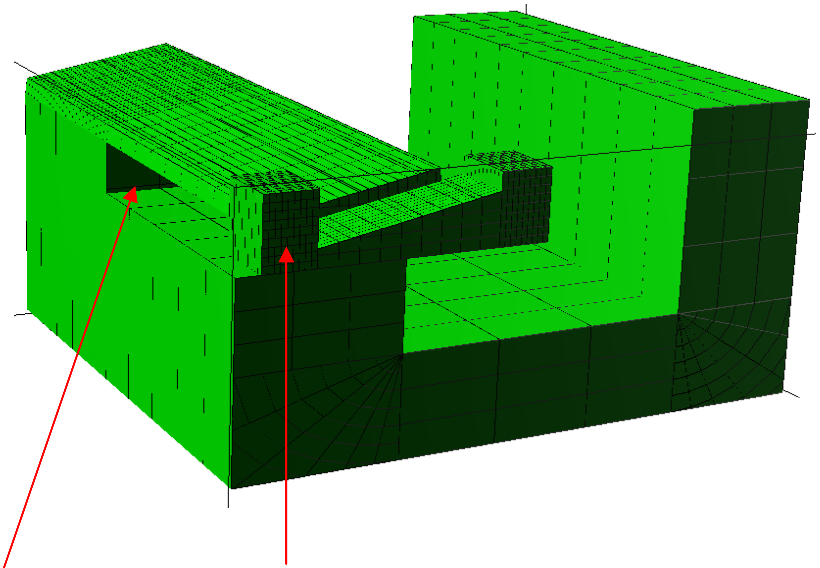
Bore radius of all magnets is minimum 15 mm.
The dipole fields scale inversely linearly with the number of achromats.
The quadrupole gradients are independent of the number of achromats.
The sextupole components are proportional to the number of achromats.





Magnetic model of the unit cell dipole magnet with varying dipole strength

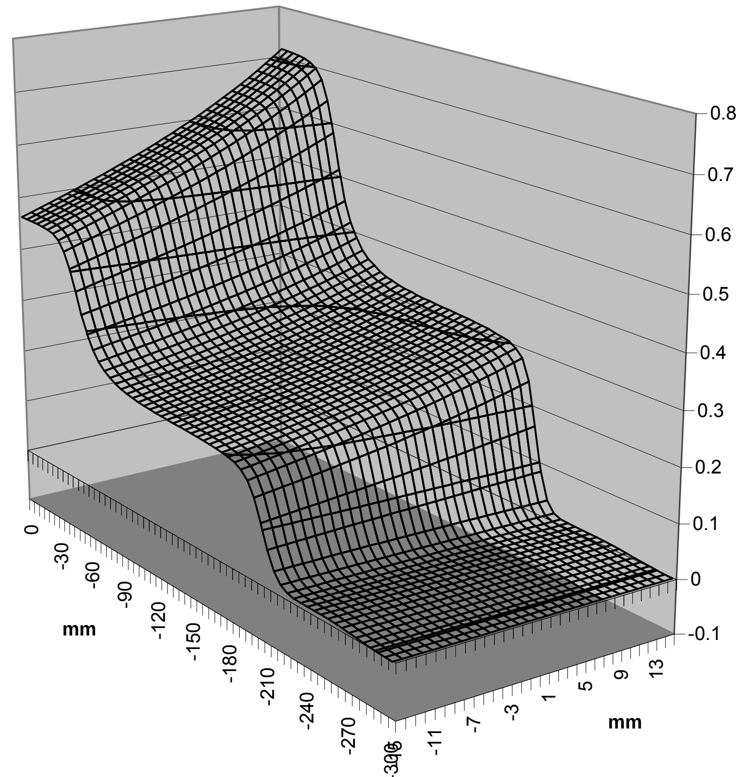
Iron yoke of the dipole magnet



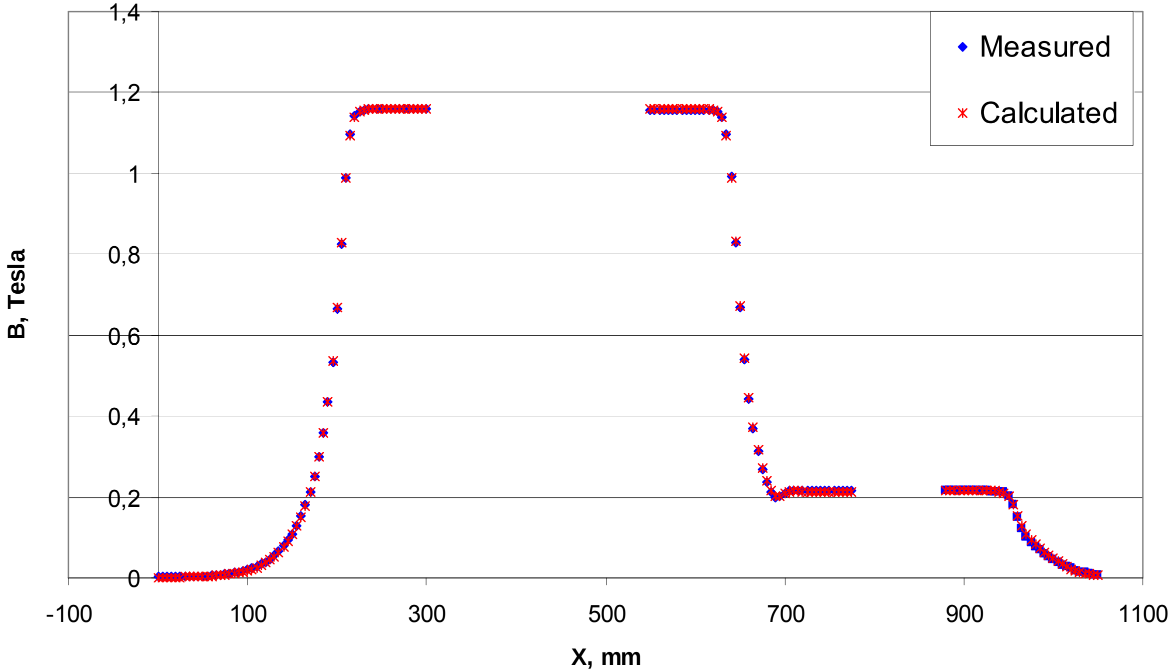
Shunt block to limit fringe fields

Floating pole face for low field region

Magnetic field distribution (20 cell)



Prototype of similar soft end dipole magnet

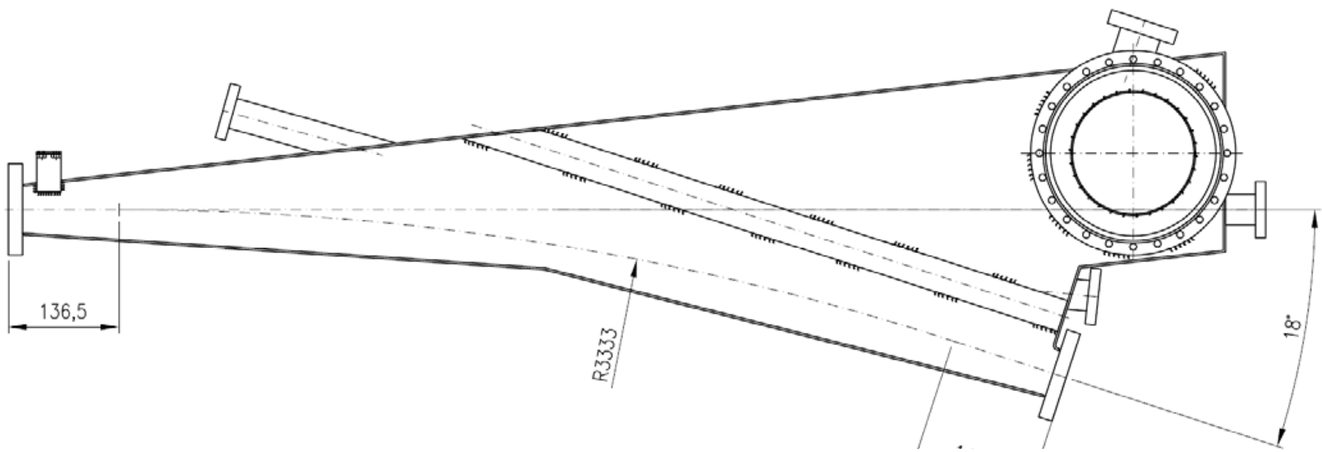


Calculated and measured magnetic fields along the centre of the magnet.

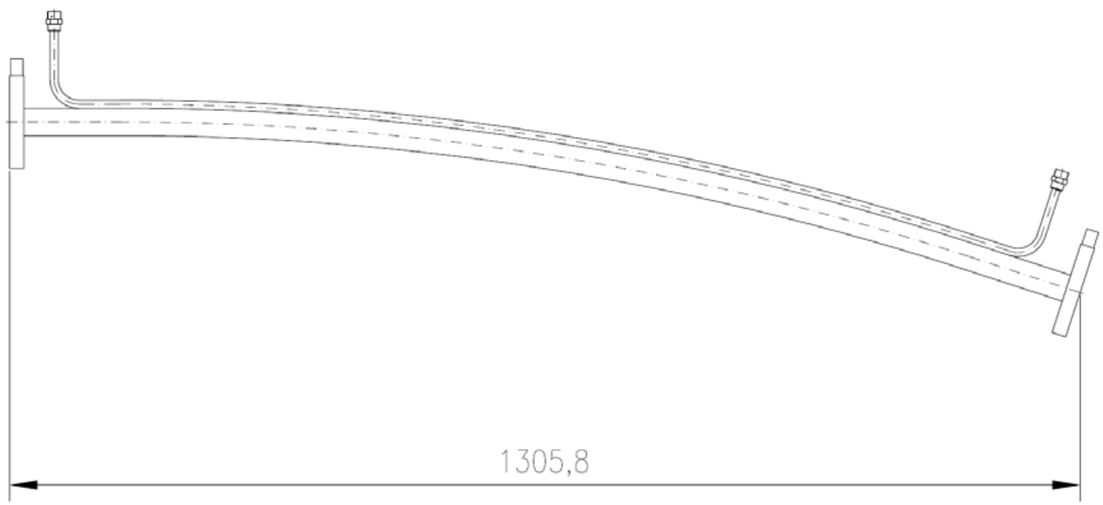
Test with NEG coated dipole chamber in MAX II

A dipole chamber of Cu with NEG coating* has been mounted into the 1.5 GeV MAX II ring in July 2007.

Standard MAX II dipole chamber made of stainless steel.

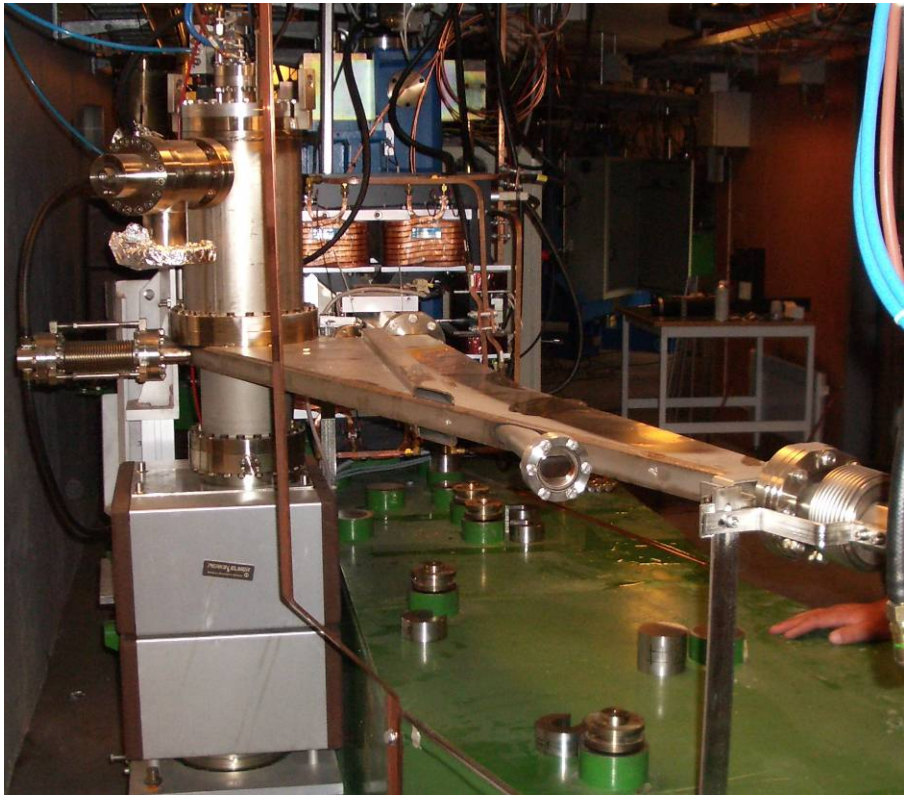


NEG coated dipole chamber of Cu under test in MAX II.

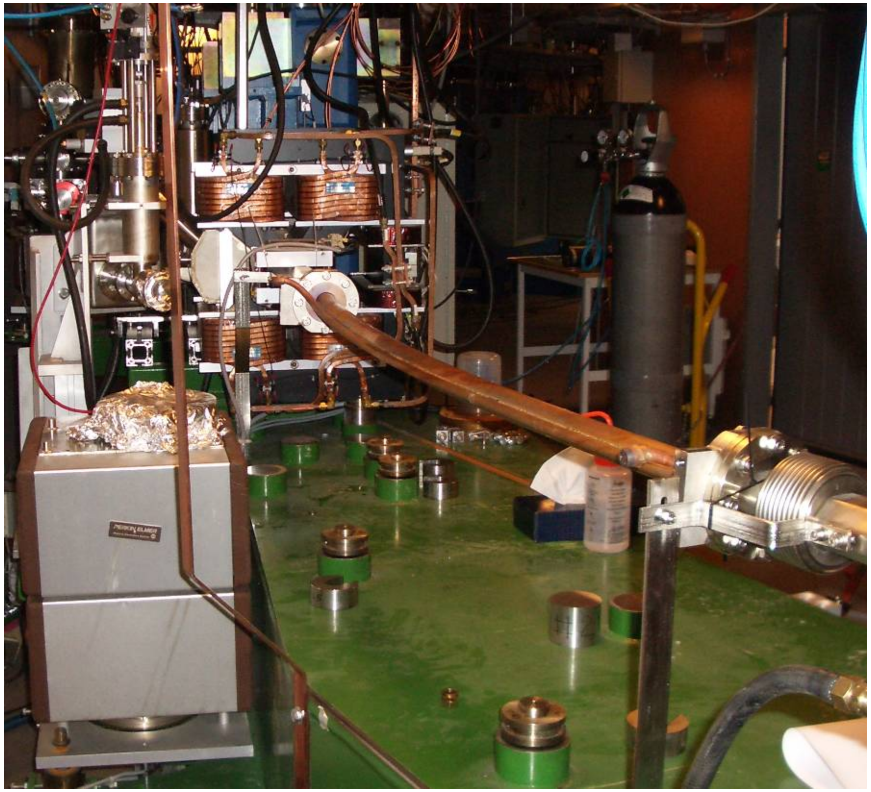


* NEG Coating made by R. Kersevan and the Vacuum Group at ESRF

Standard MAX II dipole chamber made of stainless steel.



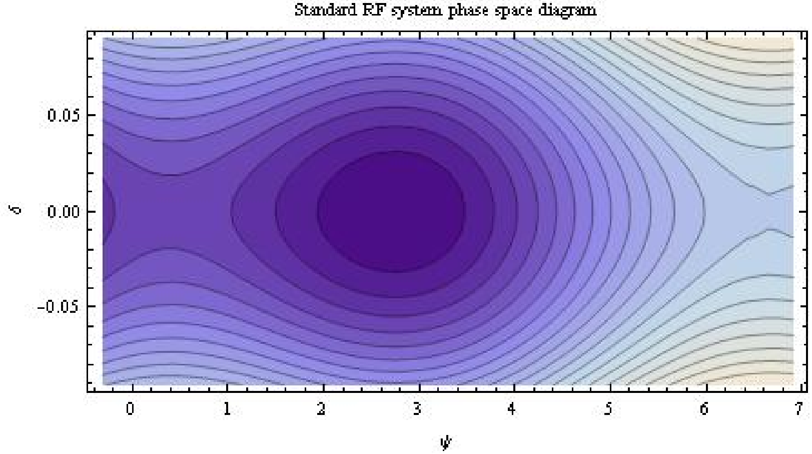
NEG coated dipole chamber of Cu .



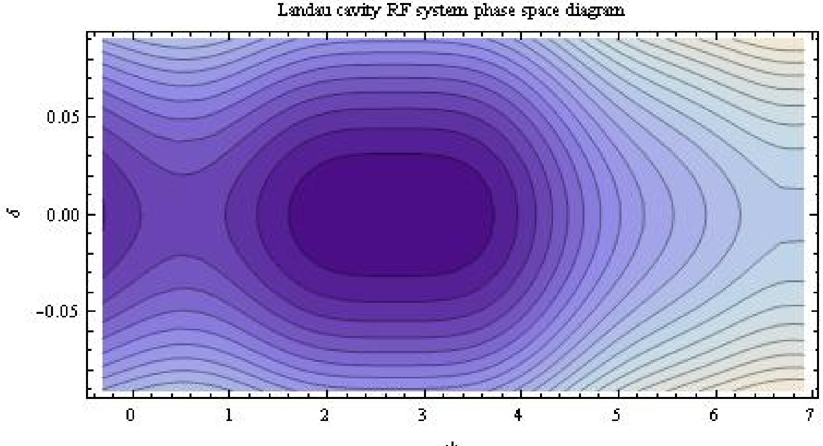
RF parameter values

	12 Achromat	20 Achromat
RF (MHz)	100	100
RF voltage (MV)	2.0	2.0
RF bucket height (%)	4.35	6.26
HC frequency (MHz)	300	300
RMS Bunch length without HC (cm)	1.4	1.1
Bunch lengthening factor due to HC	5	5

Standard RF system phase space diagram



Landau cavity RF system phase space diagram



Non linear momentum compaction . Is it a problem?

$$\frac{\Delta L}{L_0} = \alpha_c \delta + \alpha_1 \delta^2 + \xi + \mathcal{O}(3),$$

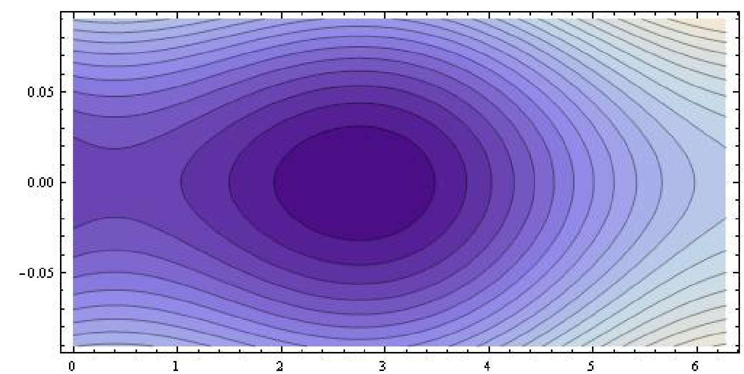
where ξ represents the momentum independent term

$$\xi = \frac{1}{4}\left(\epsilon_x \langle\gamma_x\rangle + \epsilon_y \langle\gamma_y\rangle + \epsilon_x \langle\kappa^2\beta_x\rangle\right)$$

and

$$\alpha_1 = \langle\kappa\eta_1\rangle + \frac{1}{2}\langle\kappa^2\eta_0^2\rangle + \frac{1}{2}\left\langle\eta_0'^{\,2}\right\rangle .$$

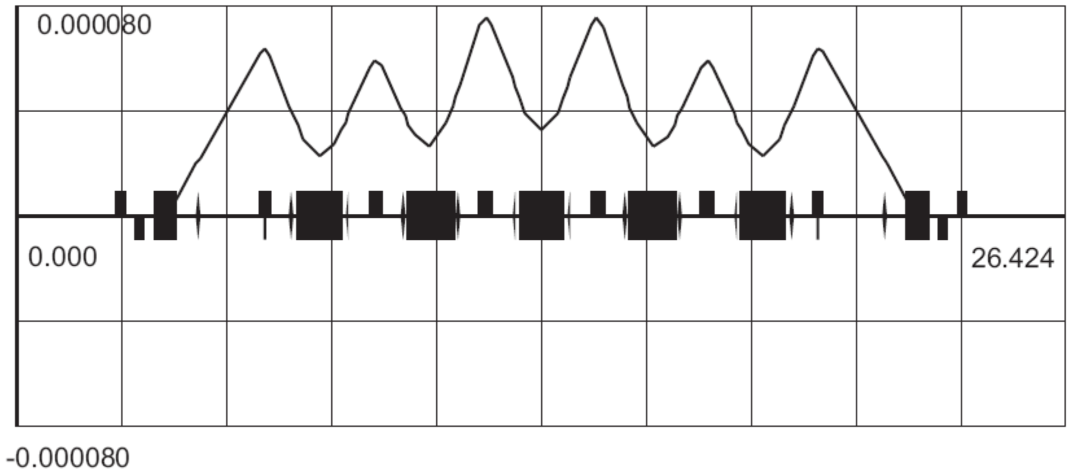
The numerical values for the constants can be found by using the TRACY code



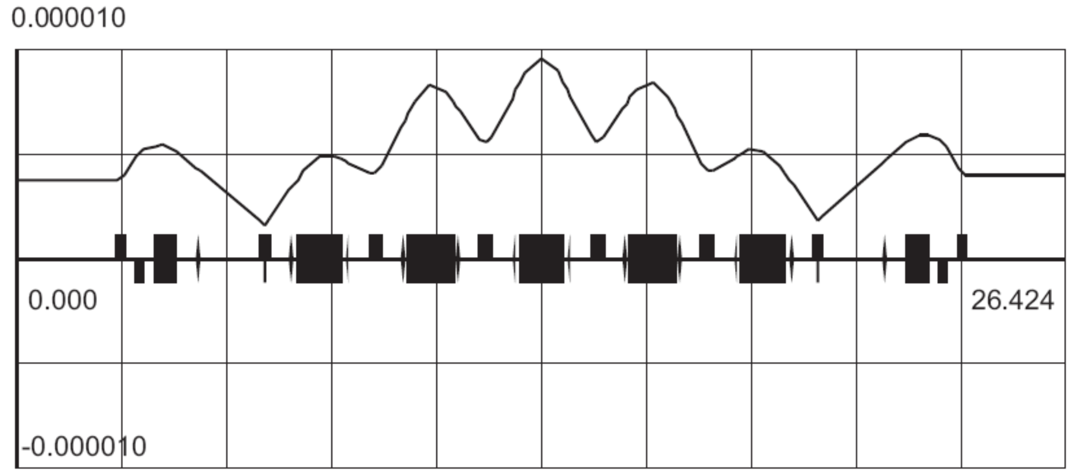
The non linear momentum compaction will not affect the bucket height.

The vertical beam size is controlled by skew quadrupoles coupling the horizontal dispersion to the vertical dispersion*

Horizontal beam trajectory [m] versus distance [m]



Vertical beam trajectory [m] versus distance [m]



*As used at the SLS

Intra beam scattering and emittance, Touschek lifetime

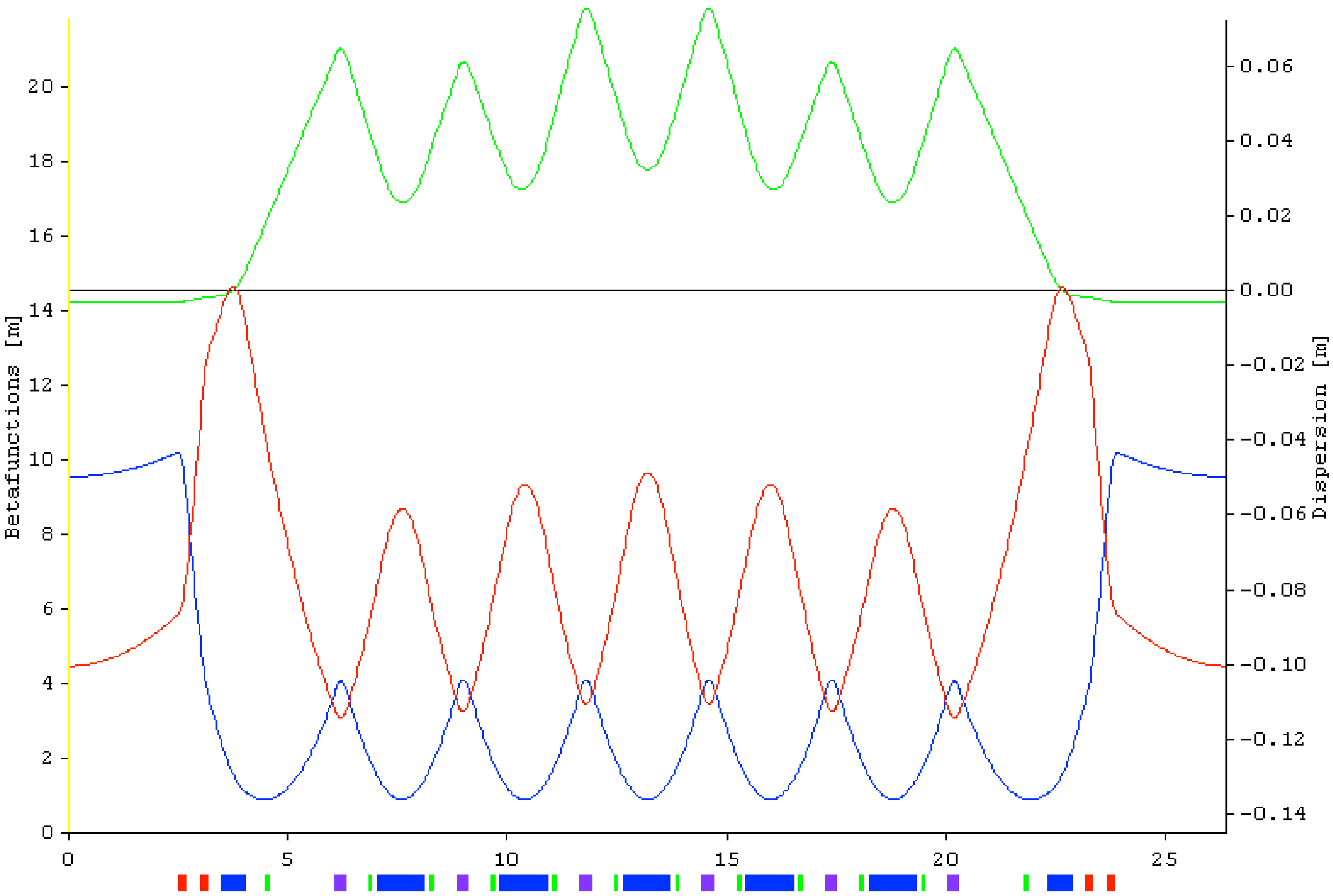
Emittance (nm rad) without/with IBS

No. of achromats	12	20
Naked lattice	1.25/1.29	0.31/0.44
Lattice + IDs	0.94/0.97	0.22/0.28
Lattice + IDs + HC	0.94/0.95	0.22/0.24

Touschek lifetimes

No. of achromats	12	20
Touschek halftime (h)	7.8	41.4
Touschek halftime with HC (h)	39	208
Inj rep rate	2/h	<1/h

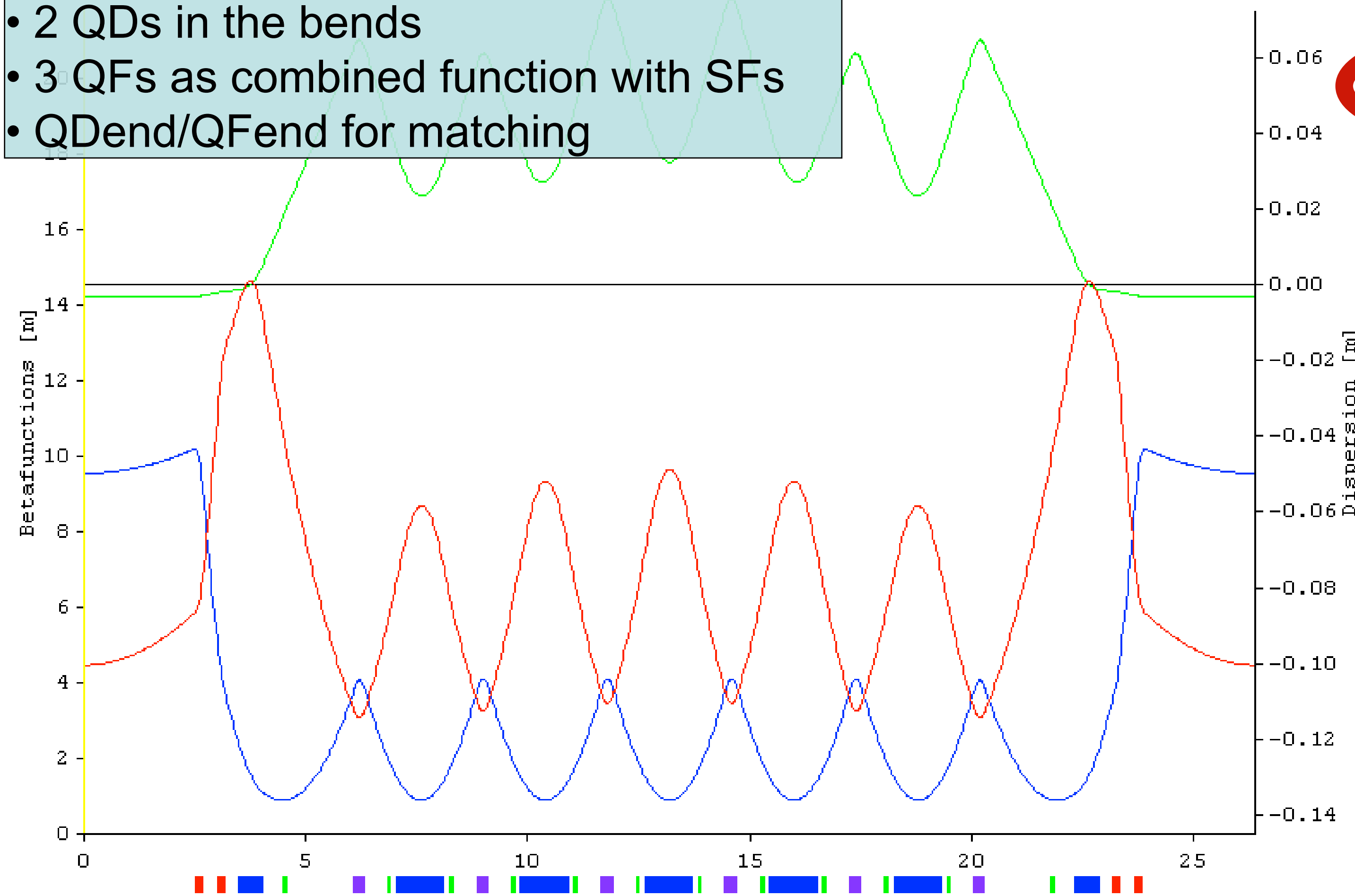
Achromat (as seen by OPA)



Line		1
Length	[m]	26.388
TuneX		2.11099
TuneY		0.71350
ChromX		-2.540
ChromY		-1.989
Alpha	[xE-3]	0.298
Jx		1.74275
Energy	[GeV]	3.000
EmitXo	[nm rd]	0.324
dE/turn	[keV]	18.1
Espread	[xE-3]	0.743
TauX	[ms]	16.709
TauY	[ms]	29.120
TauE	[ms]	23.161
Location		END
Position	m	26.388
BetaX	m	9.550
AlphaX		0.0000
BetaY	m	4.475
AlphaY		0.0000
Disp.	m	-0.0031
dD/ds	rad	0.0000
PhiX/2pi		2.1110
PhiY/2pi		0.7135
curly H	m	0.000001

Achromat (as seen by OPA)

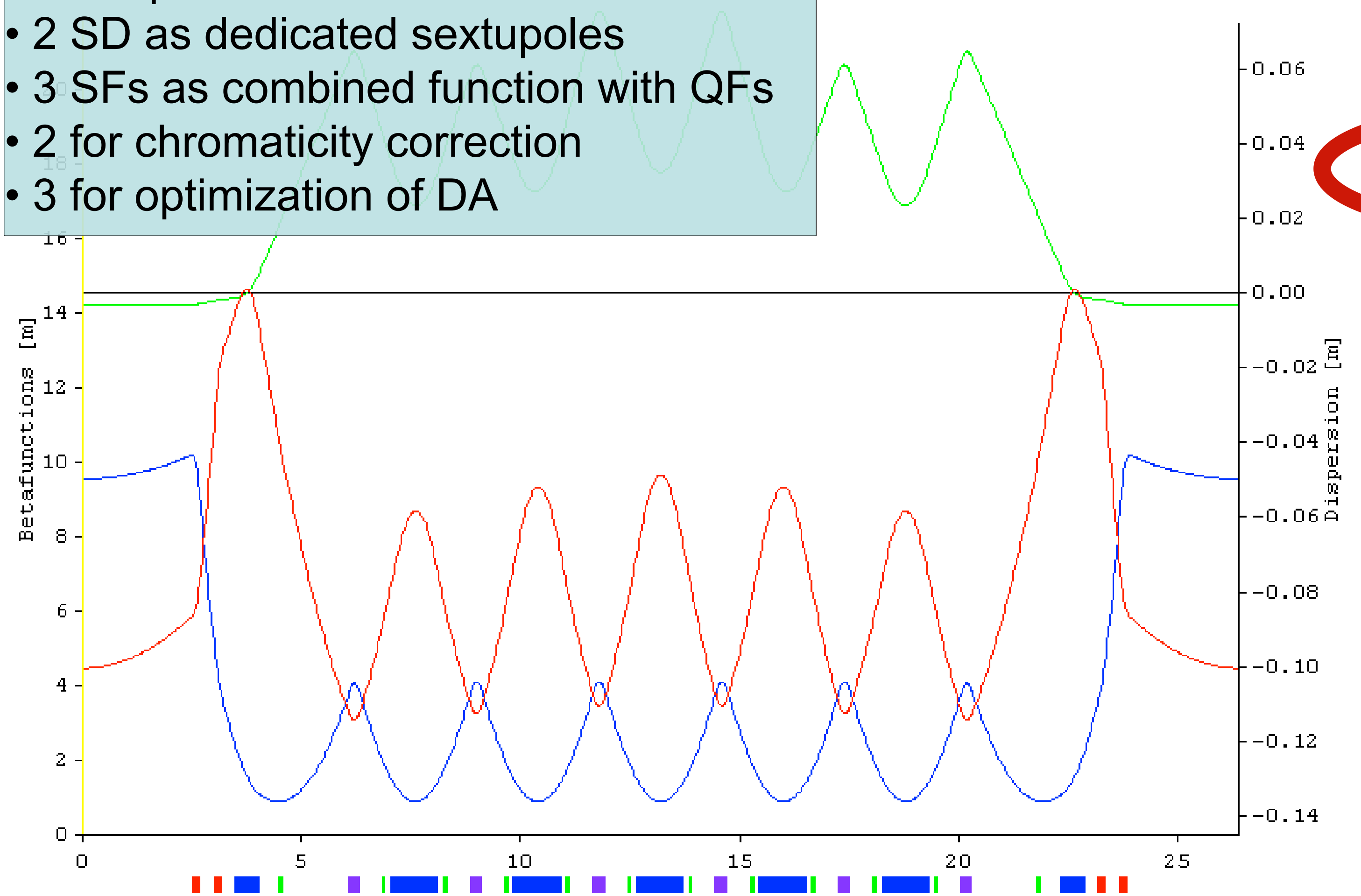
7 quadrupole families:
- 2 QDs in the bends
- 3 QFs as combined function with SFs
- QDend/QFend for matching



Line		1
[illegible]	[m]	[illegible]
TuneX		2.11099
TuneY		0.71350
[illegible]		[illegible]
ChromY		-1.989
Alpha	[xE-3]	0.298
Jx		1.74275
Energy	[GeV]	3.000
EmitXo	[nm rd]	0.324
dE/turn	[keV]	18.1
Espread	[xE-3]	0.743
TauX	[ms]	16.709
TauY	[ms]	29.120
TauE	[ms]	23.161
Location		END
Position	m	26.388
BetaX	m	9.550
AlphaX		0.0000
BetaY	m	4.475
AlphaY		0.0000
Disp.	m	-0.0031
dD/ds	rad	0.0000
PhiX/2pi		2.1110
PhiY/2pi		0.7135
curly H	m	0.000001

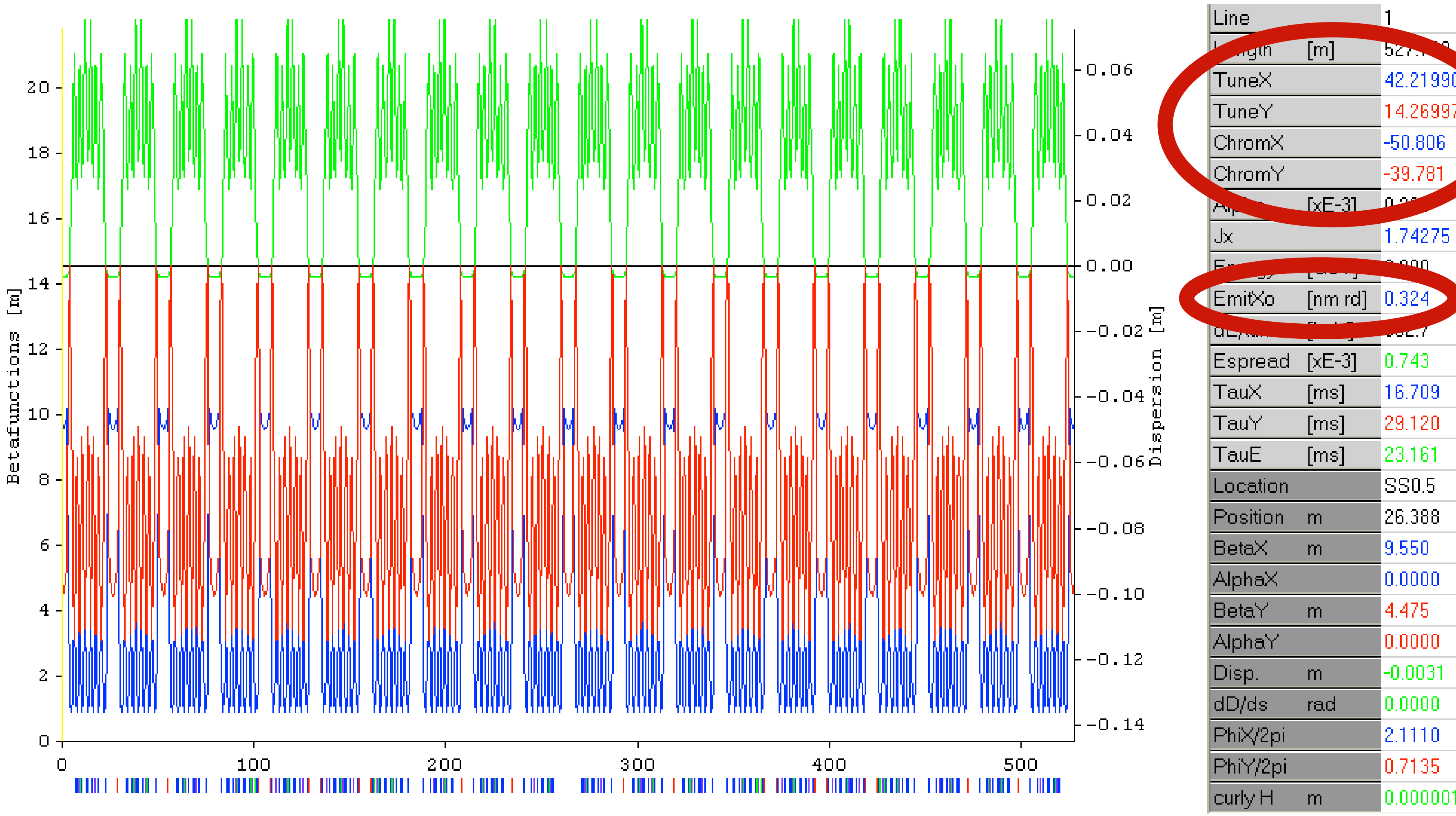
Achromat (as seen by OPA)

5 sextupole families:
- 2 SD as dedicated sextupoles
- 3 SFs as combined function with QFs
- 2 for chromaticity correction
- 3 for optimization of DA

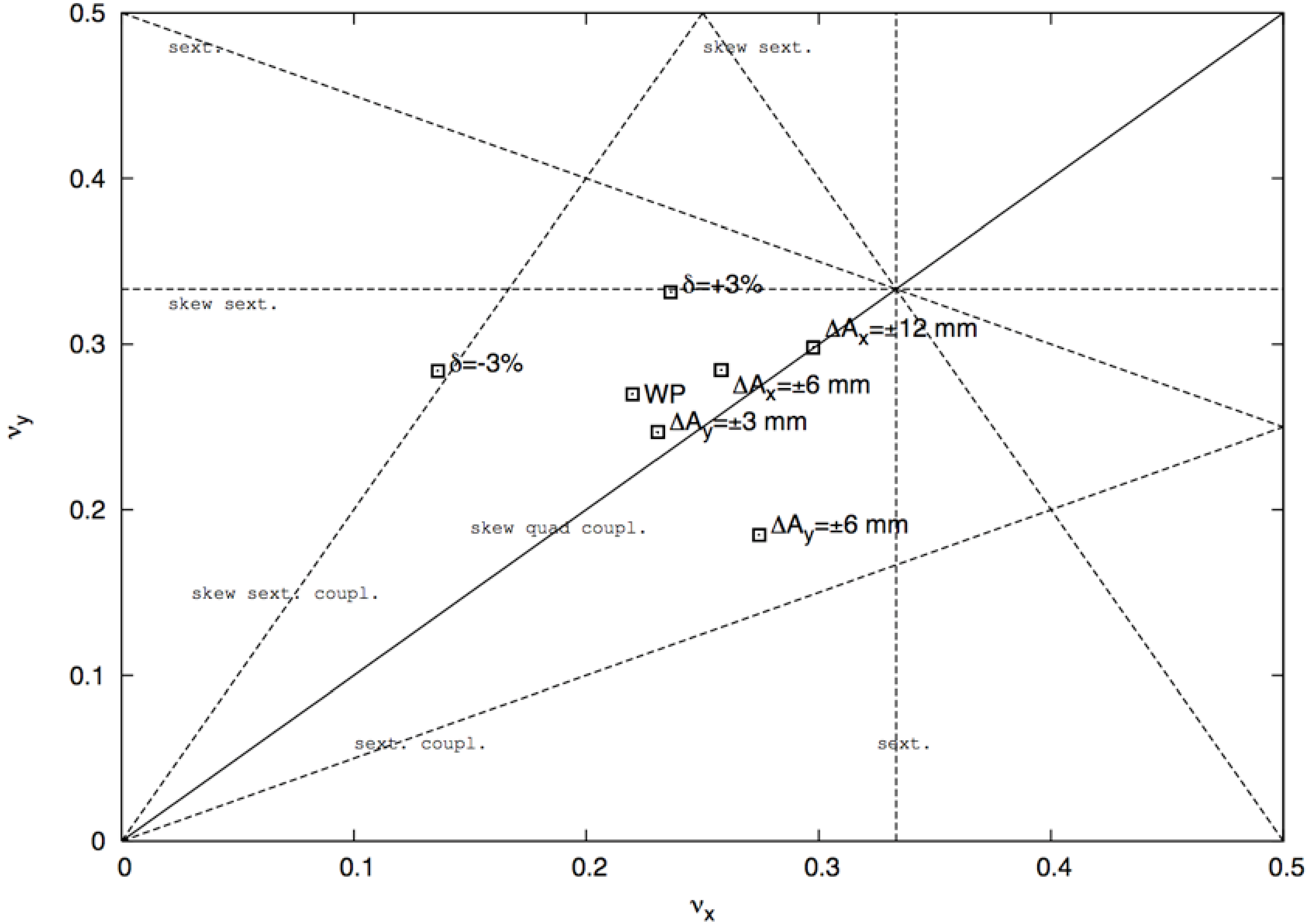


Line		1
Length	[m]	26.388
TuneX		2.11099
[illegible]		[illegible]
ChromX		-2.540
ChromY		-1.989
[illegible]	[illegible]	[illegible]
Jx		1.74275
Energy	[GeV]	3.000
EmitXo	[nm rd]	0.324
dE/turn	[keV]	18.1
Espread	[xE-3]	0.743
TauX	[ms]	16.709
TauY	[ms]	29.120
TauE	[ms]	23.161
Location		END
Position	m	26.388
BetaX	m	9.550
AlphaX		0.0000
BetaY	m	4.475
AlphaY		0.0000
Disp.	m	-0.0031
dD/ds	rad	0.0000
PhiX/2pi		2.1110
PhiY/2pi		0.7135
curly H	m	0.000001

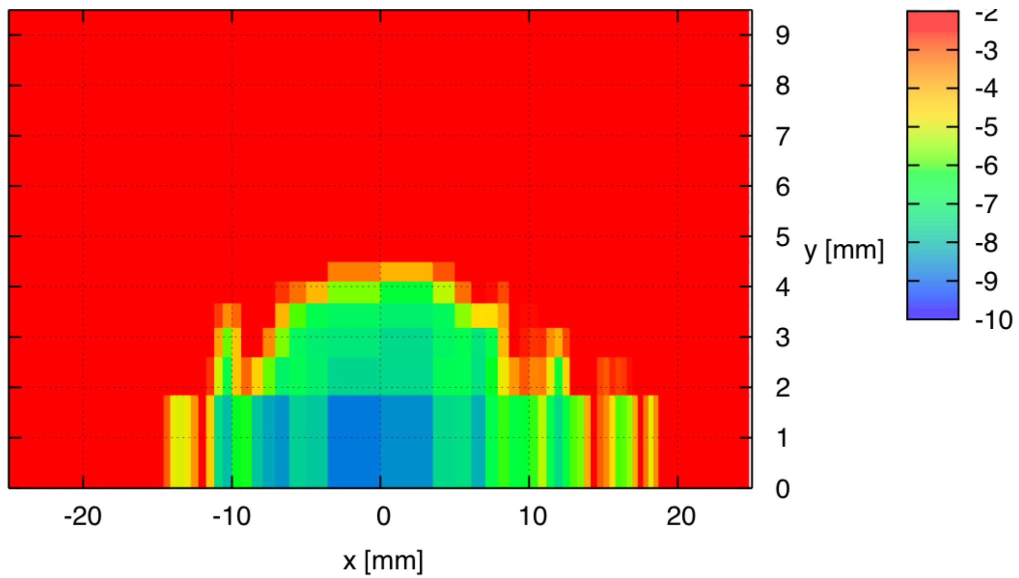
Bare Ring (as seen by OPA)

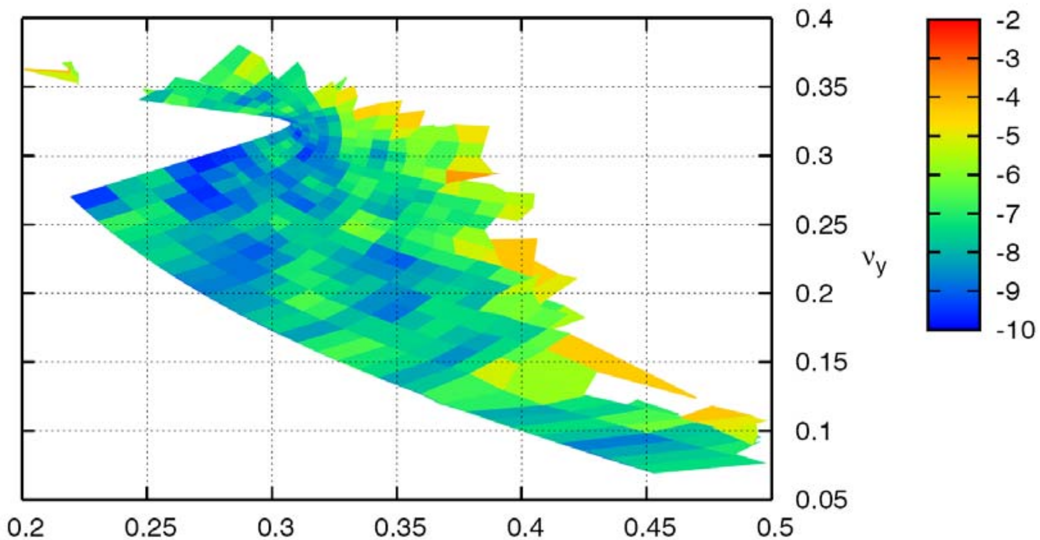


Tune Space / Tune Shifts (Tracy 3)

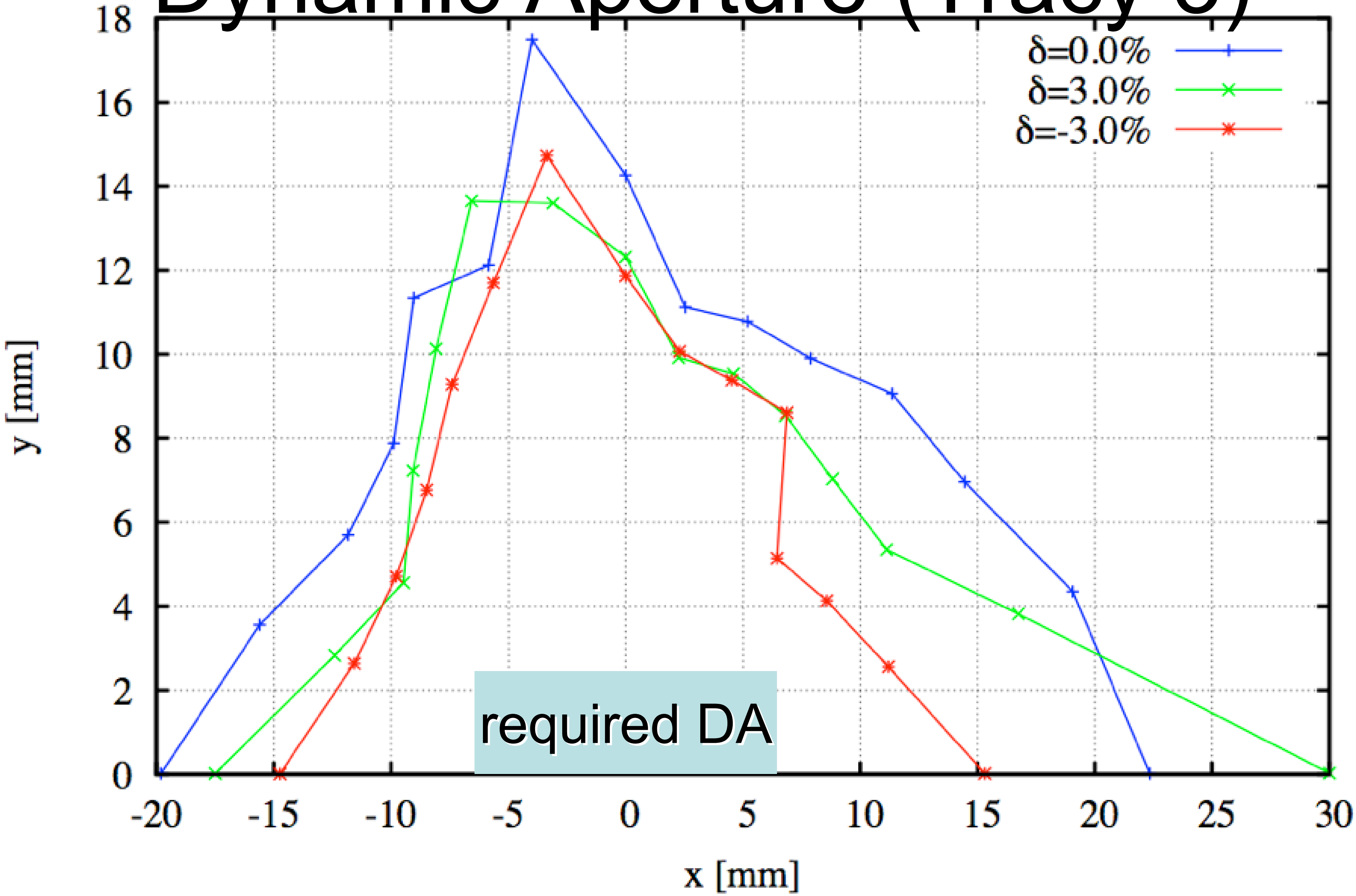


Frequency Map (on momentum)





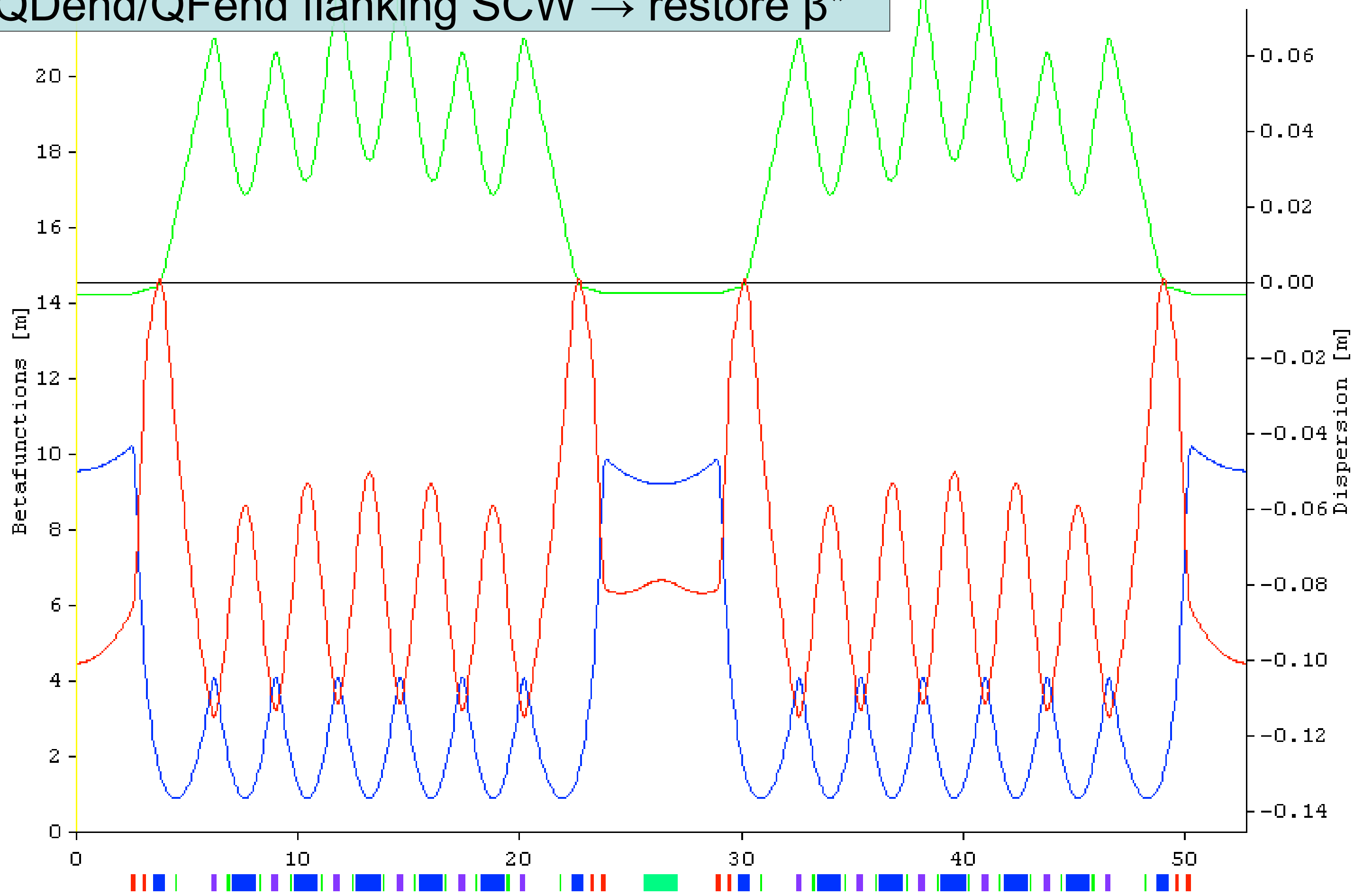
Dynamic Aperture (Tracy 3)



Non linear beam dynamics workshop, Grenoble May 26, 2008, E. Wallén.

Introduce Super-Conducting Wiggler

Adjustments:
- QDend/QFend flanking SCW → restore β*

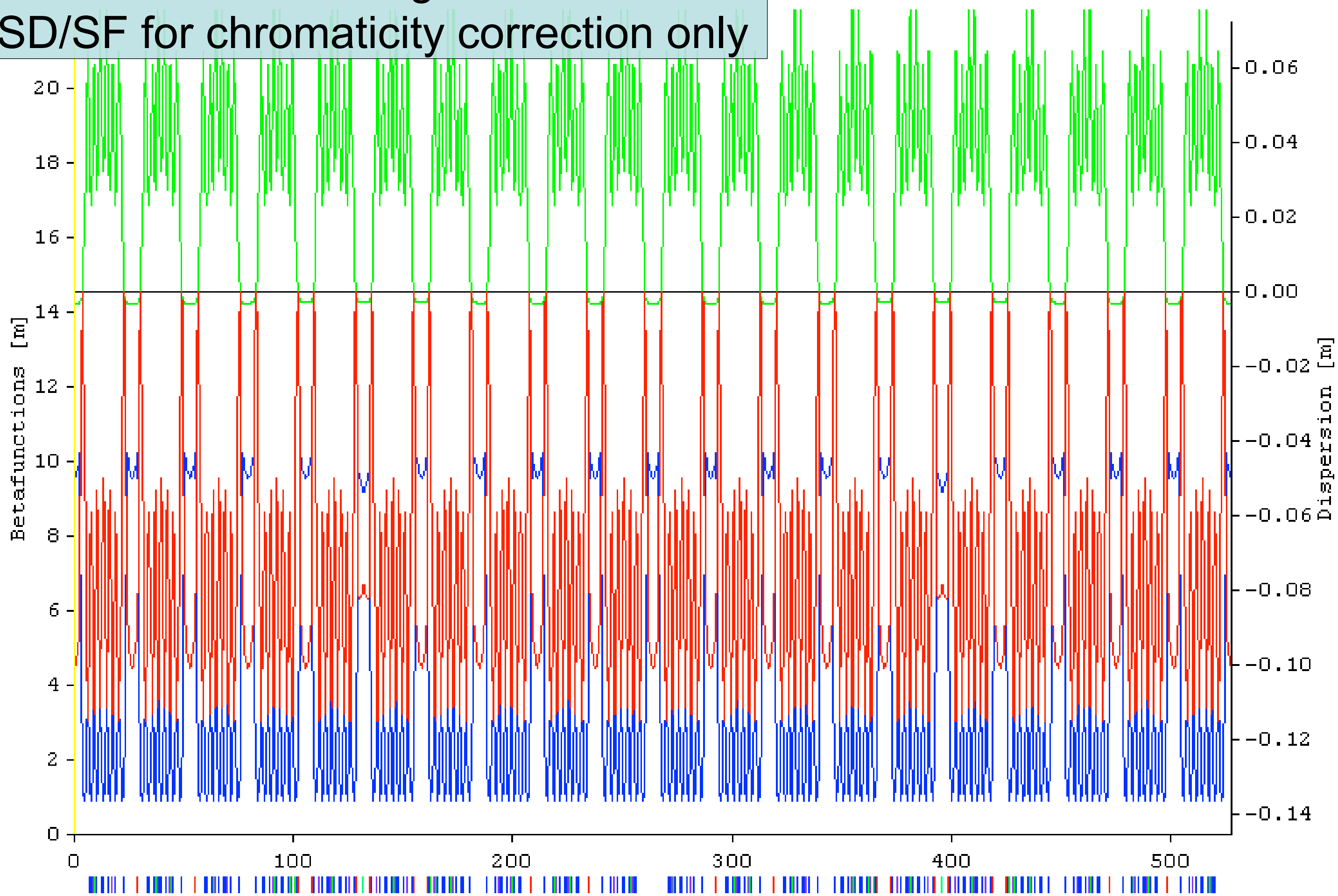


Line		1
Length	[m]	52.776
TuneX		4.22447
TuneY		1.39454
ChromX		-5.051
ChromY		-3.883
Alpha	[xE-3]	0.298
Jx		1.20024
Energy	[GeV]	3.000
EmitXo	[nm rd]	0.215
dE/turn	[keV]	134.7
Espread	[xE-3]	1.304
TauX	[ms]	6.531
TauY	[ms]	7.839
TauE	[ms]	4.355
Location		END
Position	m	52.776
BetaX	m	9.570
AlphaX		0.0000
BetaY	m	4.474
AlphaY		0.0000
Disp.	m	-0.0030
dD/ds	rad	0.0000
PhiX/2pi		4.2245
PhiY/2pi		1.3945
curly H	m	0.000001

3.54 T, 61 mm, 24.5 periods

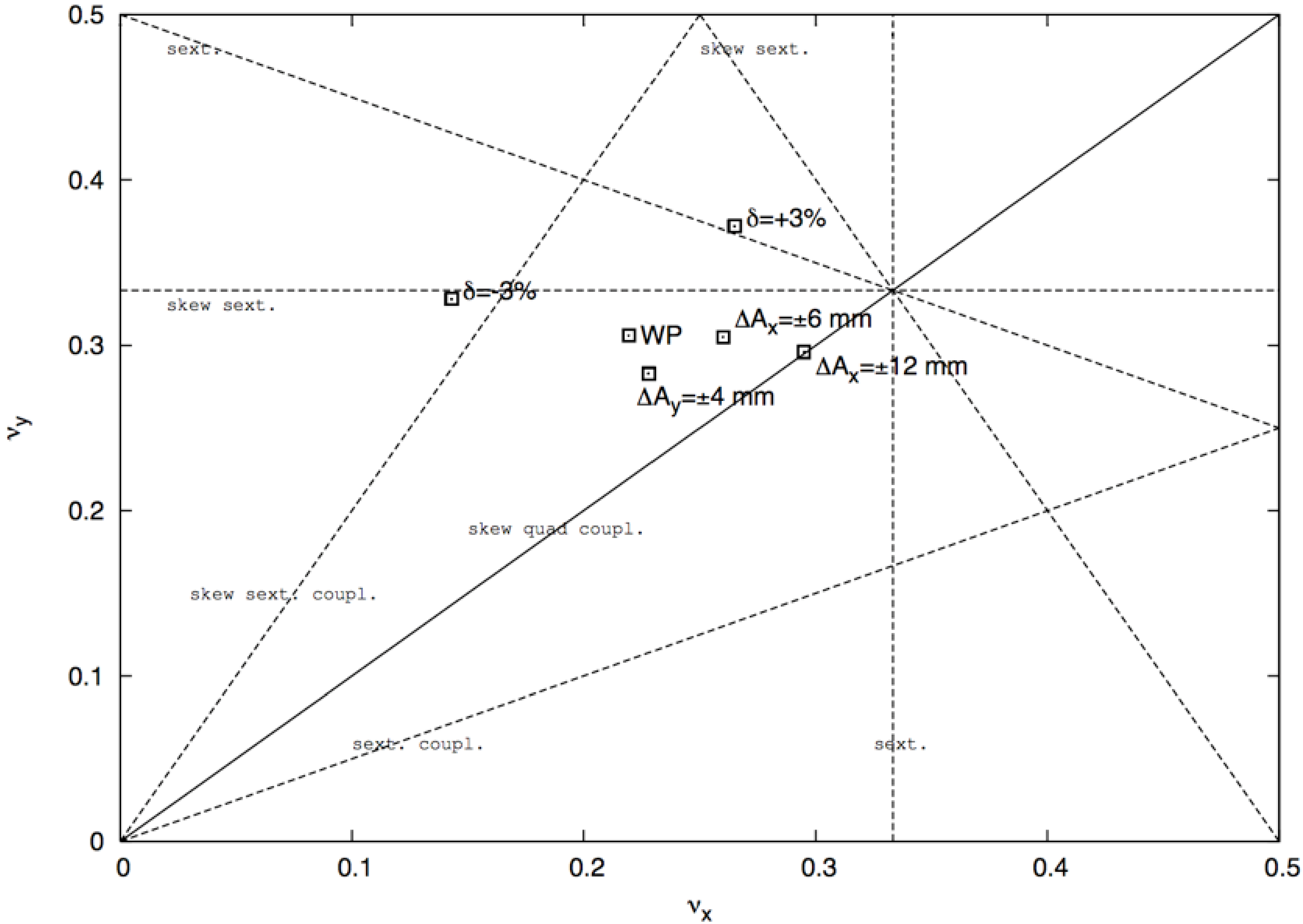
2 SCW Installed in Ring

Adjustments:
- QF/QD → restore original WP
- SD/SF for chromaticity correction only

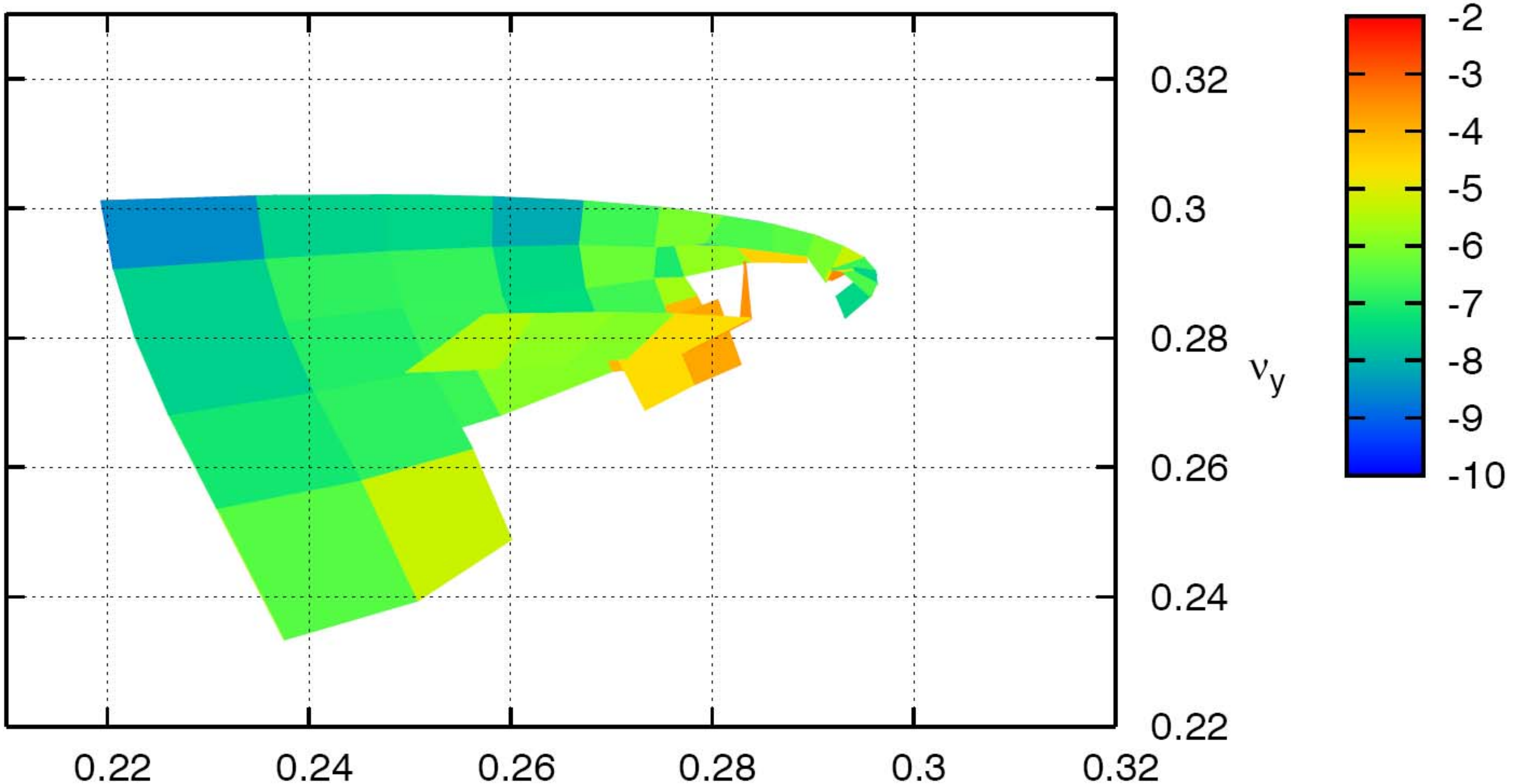


Line		1
Length	[m]	[illegible]
TuneX		42.21996
TuneY		14.26996
ChromX		[illegible]
ChromY		-39.510
Alpha	[xE-3]	0.298
Jx		1.48208
Energy		[illegible]
EmitXo	[nm rd]	0.281
dE/turn		[illegible]
Espread	[xE-3]	1.099
TauX	[ms]	12.734
TauY	[ms]	18.873
TauE	[ms]	12.433
Location		QFEND
Position	m	50.276
BetaX	m	10.225
AlphaX		0.2611
BetaY	m	5.872
AlphaY		0.5589
Disp.	m	-0.0030
dD/ds	rad	0.0000
PhiX/2pi		4.1807
PhiY/2pi		1.3540
curly H	m	0.000001

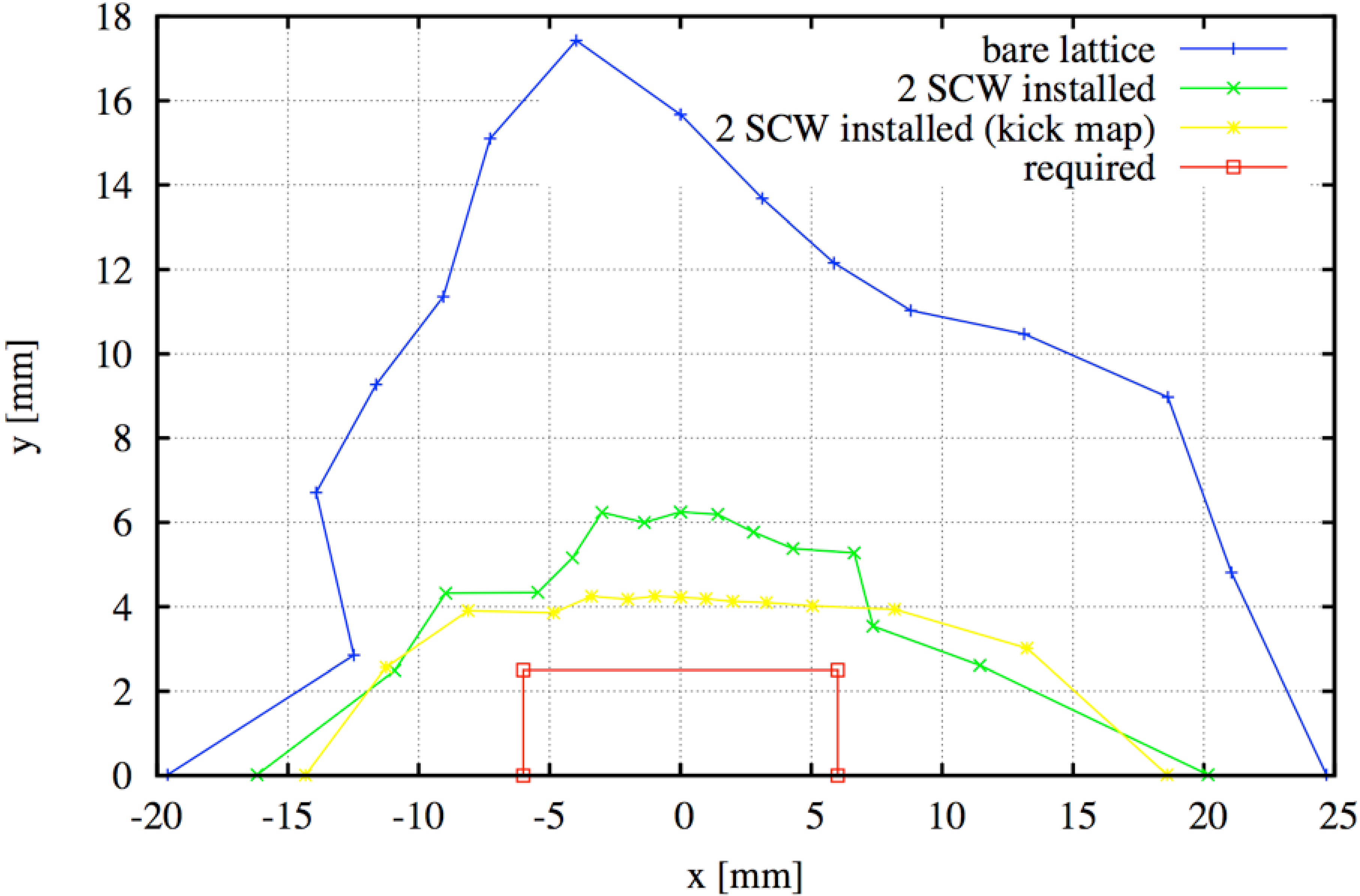
Tune Space / Tune Shifts (Tracy 3 with kick map)



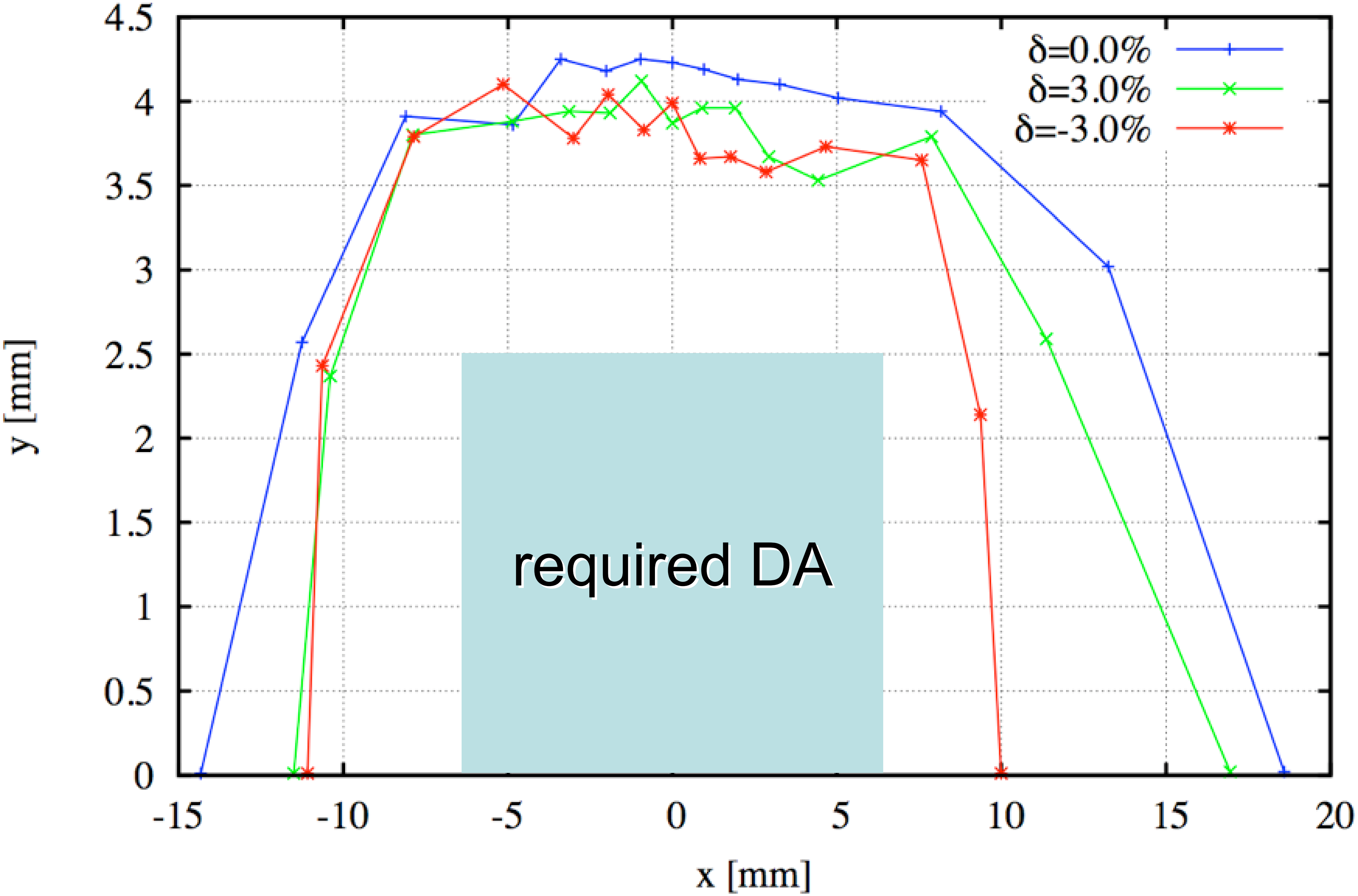
Frequency Map (on momentum)



Dynamic Aperture (Tracy 3, δ=0%)



Dynamic Aperture (Tracy 3 with kick map)



Misalignments → Closed Orbit Distortion